

# **Conservative and Non-Conservative Variability in the Inherent Optical Properties of Dissolved and Particulate Components in Seawater**

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Award #: N00014-95-1-0331

## **LONG TERM GOAL**

The long term goals of this project are to develop methods for separating the observed variability in the inherent optical properties (IOPs) into conservative and non-conservative components, with the goal to use optical measurements to simultaneously provide information about the physical and bio/chemical processes in the water column, respectively.

## **SCIENTIFIC OBJECTIVES**

Optical measurements originated with the single wavelength beam attenuation coefficient,  $c(\lambda_o)$ , which was used as an indicator of suspended material in seawater. The capability exists now to measure the spectral  $c$  and separate it into its absorbing and scattering components,  $a$  and  $b$ . Towards the goal of identifying conservative and non-conservative variations in the IOPs as indicators of physical and bio/chemical processes in the water column, it is necessary to deconvolve further the bulk  $a$  and  $b$  coefficients to explicitly identify the components responsible for optical variability. Thus, the scientific objectives of this projects which are to: (1) separate in situ the bulk IOPs into size ranges with the hypothesis that distinct classes of particulate material can be separated by size and that these classes will be acted upon by different physical, chemical and biological processes; (2) separate the size fractionated  $a$  coefficient into phytoplankton and non-phytoplankton components based upon the spectral shapes of the absorption coefficients (Roesler et al. 1989) each of which will certainly be prone to different physical, chemical and biological processes; (3) quantify the relative contributions of the size-fractionated components in the major water masses that occupy the shallow continental shelf waters; (4) quantify the optical variability of these size-fractionated component IOPs within and between these major water masses; (5) relate the conservative and non-conservative optical variations to specific physical and bio/chemical processes; (6) quantify the time scales of vertical mixing using non-conservative optical variability.

## **APPROACH**

An integrated optical profiling system, consisting of three WETLabs ac9s (one donated by Dr. Heidi Sosik), a WETLabs safire (data collected for Dr. Paula Coble), an FSI micro CTD, a and a WETLabs SuperMODAPS, was deployed with the ship's CTD/rosette package to obtain optical and physical measurements concurrent with discrete water samples. In situ fractionation of the IOPs was obtained by placing filter cartridges on the intake ports of the ac9s. Multiple profiles per cast enabled more than three size fractions to be obtained. Filter pore sizes were 0.2, 1, 3, 5, and 10 $\mu$ m.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>1998</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-1998 to 00-00-1998</b>	
4. TITLE AND SUBTITLE <b>Conservative and Non-Conservative Variability in the Inherent Optical Properties of Dissolved and Particulate Components in Seawater</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>University of Connecticut, Department of Marine Sciences, 1084 Shennecossett Rd, Groton, CT, 06340</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002252.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>8</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

All water samples were analyzed immediately upon collection except for nutrients samples (nitrate, phosphate, silicate) which were immediately frozen and stored for later analysis. Pigment concentrations were determined fluorometrically and by HPLC. Particle composition, concentration, and size distribution were determined with a Galai CIS100 Particle Analyzer. Absorption coefficients for colored dissolved organic material (CDOM) were measured spectrophotometrically on 0.7- $\mu\text{m}$  filtrate. Particulate absorption coefficients were determined using the quantitative filter technique with correction for pathlength amplification (Roesler, 1998). The particulate absorption coefficients were separated into contributions by phytoplanktonic pigments and tripton using the methanol extraction method (Kishino et al., 1985).

Size-fractionated particulate absorption coefficients measured in situ were partitioned into phytoplankton and tripton components (Roesler et al., 1989) with modifications for the ac9 (Roesler and Zaneveld, 1993). Size-fractionated scattering and size-fractionated component-specific absorption coefficients were determined for the major water masses occurring at the station (as identified by TS relationships). Total optical variability is separated into conservative (i.e. between water masses) and non-conservative (i.e. within water masses) components. Conservative optical variability will be used to investigate the physical processes associated with advection, mixing and passage of internal waves and solitons. Non-conservative optical variability (photo-oxidation of surface CDOM, phytoplankton photoacclimation) will be used to investigate the time scales of mixing processes.

## **WORK COMPLETED**

Two three-week cruises were successfully undertaken in July-August 1996 and April-May 1997 to the continental shelf south of Nantucket (40°30' N, 70°30' W). All water sample analyses have been completed. Over one hundred optical casts were performed per cruise yielding over three profiles per day of at least three size classes of IOPs. All optical profiles, collected with the MODAPS, have been extracted and merged with the CTD data into separate IOP and spectral fluorescence data files (the latter of which was given to Paula Coble).

Processing of the merged MODAPS data has proven more difficult than originally anticipated. The integration of a CTD and three ac9s with different filter cartridges necessitates interactive data processing of each cast. The processing steps were as follows: remove all data for which the package did not descend monotonically with time (to remove effects of pressure changes on the pumps); bin data at 1Hz intervals (minimum resolution of the CTD); take median of the 1Hz binned data (first order data despiking); bin data in 10 cm intervals (minimum resolution of pressure sensor); take median of the 10 cm bins (second order despiking); interpolate to 25 cm resolution; temperature correct the absorption and attenuation measurements at 715 nm (Pegau and Zaneveld, 1993) using laboratory-determined instrument-specific temperature coefficients; correct absorption spectra for spectral scattering (Roesler and Zaneveld, 1993). Processing of the data are complete to this stage. Initial quantification of the size-fractionated component-specific IOPs for individual water masses has been performed on a subset of the data (the noon time casts) from each cruise.

## RESULTS

### *Highly Stratified Conditions*

The water column encountered during the summer cruise was characterized by highly stratified conditions driven primarily by temperature (Fig. 1). Vertical variability in the hydrography far exceeded horizontal variability. Against this stable condition was the occasional appearance of advected continental slope water characterized by increased salinity values. The IOPs exhibited strong vertical structure, as expected by the stable physical conditions, but also exhibited large temporal variations associated with the pulses of slope water (Fig. 2). Waters were clearest in the upper 15 to 20 m and there was a subsurface layer from approximately 40 to 55 m that was also relatively clear. Enhanced attenuation and variability in attenuation was observed in the 20 to 30 m layer and the bottom 10 m.

Separation of the absorption coefficient into optically active components indicates that much of the variability in the 20 to 30 m layer is due to phytoplankton at associated CPM (Fig. 3). CDOM was lowest in the upper mixed layer and relatively uniform beneath the pycnocline. CPM exhibited the greatest spatial and temporal variability. It is this fraction that is most coherent with the attenuation and salinity. Previous results (see last year's report) indicate that this fraction located below 40 m is comprised of particles larger than 10  $\mu\text{m}$  in diameter and is associated with the slope water; it is likely resuspended inorganic sediments. That which is located just beneath the thermocline is comprised of particles less than 10  $\mu\text{m}$  in diameter, is coherent with the phytoplankton component and is likely organic particles.

### *Unstratified Conditions Leading to the Onset of Stratification*

The water column encountered during the spring cruises was weakly stratified with no identifiable thermocline. Stratification increased throughout the cruise with periods of strong mixing (Fig. 4). During this period the temporal variability was stronger than the vertical variability. As was found during the summer cruise, there is a subsurface layer between 30 and 50 m that remains optically clear throughout the sampling period (Fig. 5). Above this layer, the attenuation exhibited strong variations with time, the highest values found during the middle period of the cruise. Absorption generally decreased with time, and the decrease was observed in all of the optically active components (Fig. 6). The variations in the surface water attenuation were most coherent with those observed in the phytoplankton component although the magnitude of the latter is not sufficient to explain the variations in  $c$ . This does indicate that the other fractions which are responsible for the variations are coherent with the phytoplankton.

HPLC analyses of surface waters indicate a general trend towards decreasing pigment throughout the cruise (McLeroy-Etheridge and Roesler, 1998). More interesting is that while the phytoplankton absorption spectra did not exhibit large variations in shape, there were significant changes in the phytoplankton community. Two pigment-based taxonomic communities were identified, one rich in fucoxanthin (diatoms) and one rich in peridinin (dinoflagellates). The latter was also associated with small chlorophytes and cyanobacteria. These two communities were observed to be temporally incoherent and the temporal patterns were associated with the physical structure throughout the period of observation. The diatom community was maximal during the short periods of destratification while the other mixed community was maximal during the short periods of stratification. During the last day of the cruise, when stratification was maximal, the

two communities became temporally coherent (sampling resolution was 2h over the 24 hour period).

## **IMPACT/APPLICATION**

In order to understand the variability in bulk inherent optical properties, it is necessary to deconvolve the signal into the components that comprise the bulk material. The approach presented in this project is to quantify the optical variability associated functional groups of different size classes, thereby increasing the ability to interpret bulk optical variability with greater confidence. More importantly, the component optical variability can be attributed to conservative and non-conservative processes providing additional means to study physical and biological processes in the ocean.

## **TRANSITIONS**

The in situ size fractionation, developed and tested in 1993 by Scott Pegau, Ron Zaneveld and myself, is now being used by most ac9 owners. Further fractionation into functional groups has been used in NRL-funded LOE and COPE experiments in collaboration with Dr. A. Weidemann.

## **RELATED PROJECTS**

1. Jennifer Simeon, my technician, and I have quantified the optical variability along the upwelling region of the Equatorial Pacific (Simeon et al., submitted); ship time on the Zonal Flux Experiment provided by Jim Murray (UW).
2. I am investigating the relationship between IOPs and irradiance reflectance in collaboration with Norman McCormick (UW) and his student, Bob Leathers (Leathers et al, submitted).
3. Davnet Shaffer, my student, and I are investigating the utility of single excitation/emission fluorescence signatures to identify and trace the source of DOM in Long Island Sound and Chesapeake Bay(NRL-sponsored COPE) (Shaffer and Roesler, in prep.) .

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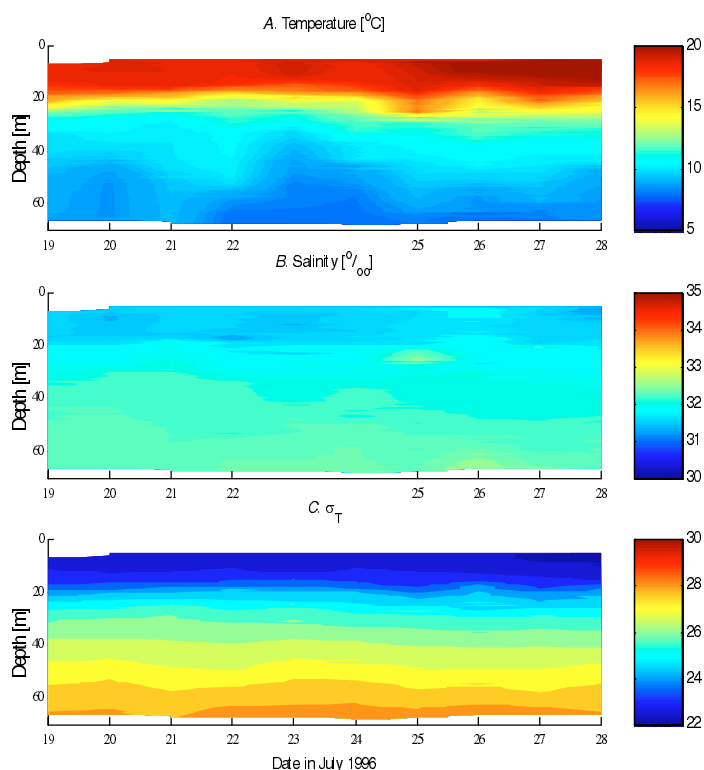
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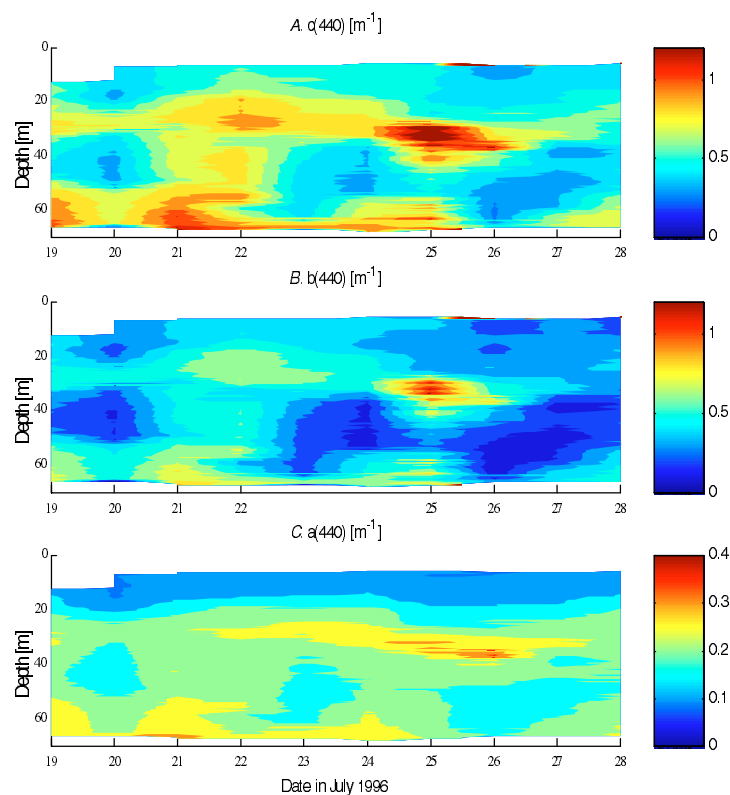
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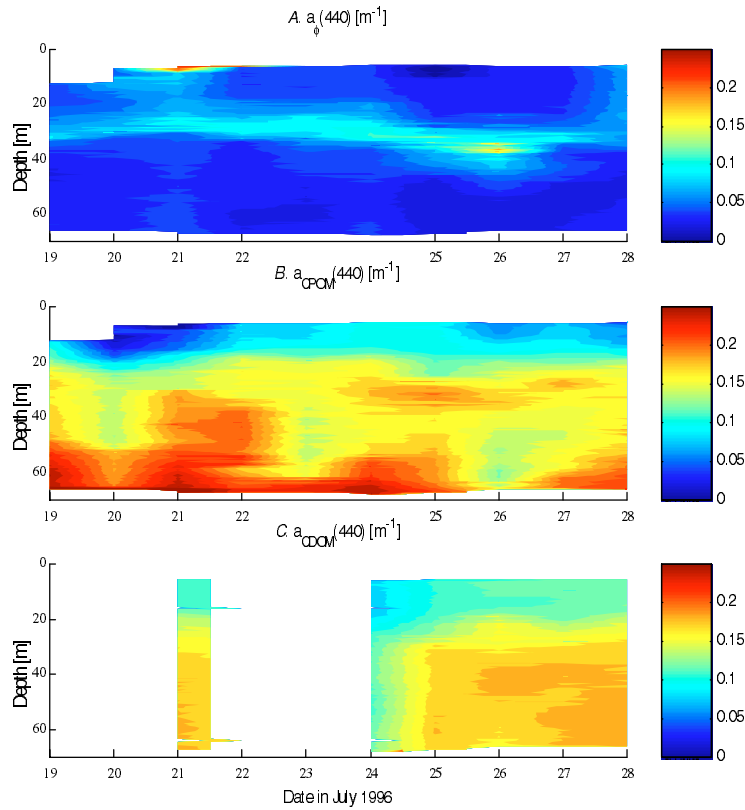
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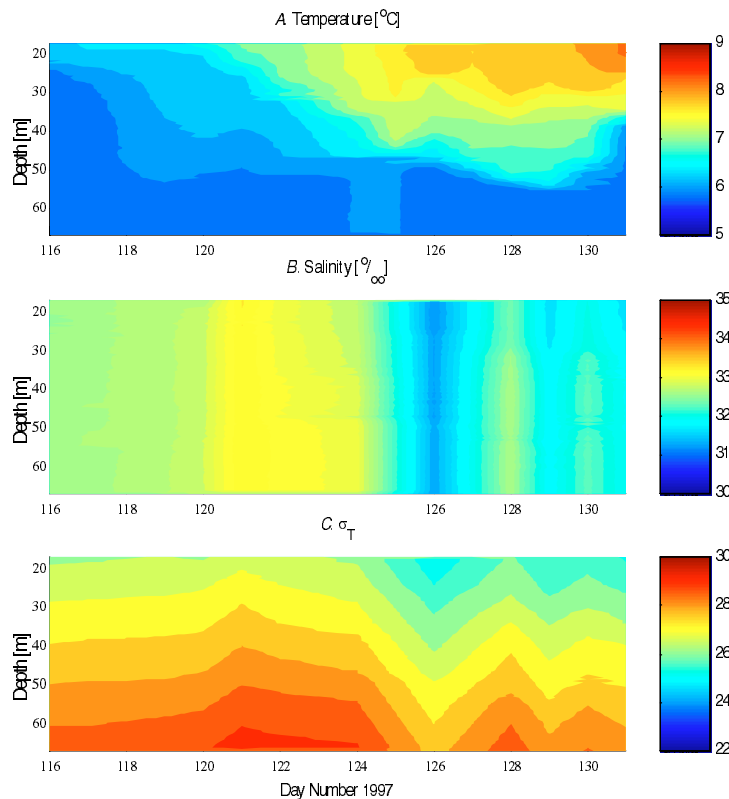
**Figure 1. Hydrographic conditions during the first CMO cruise in July 1996 prior to Hurricane Edouard. A. Temperature, B. Salinity, C.  $\sigma_T$ . Data shown is from daily noon time casts. The data have not been detided nor has there been corrections for the plentiful internal waves which were observed during this period.**



**Figure 2. Inherent optical properties measured during the first CMO cruise in July 1996 prior to Hurricane Edouard. A. Attenuation, B. scattering, and C. absorption at 440 nm were measured in situ with an ac9. The scale for absorption is half that of the attenuation and scattering.**

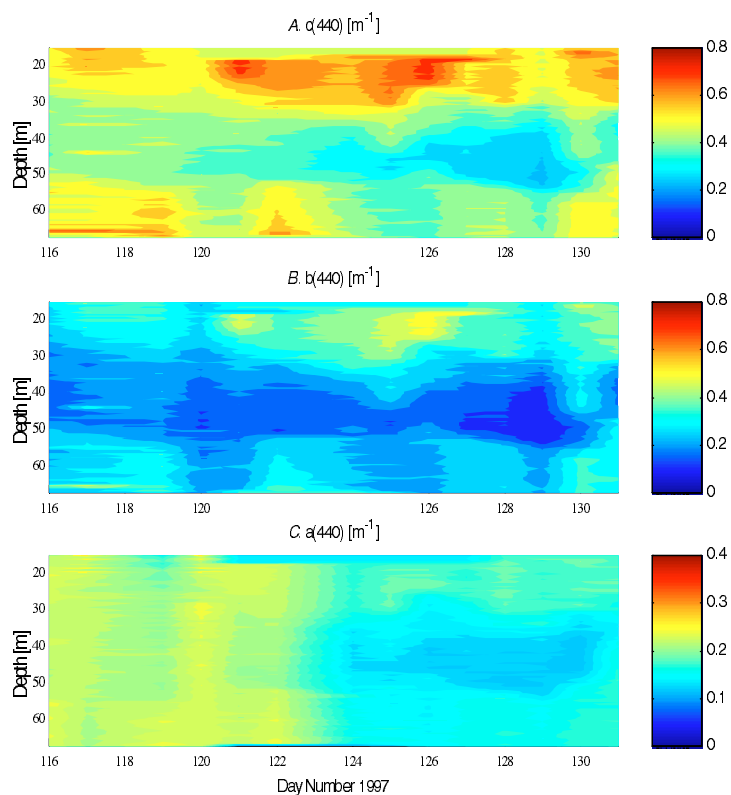


**Figure 3. Component absorption at 440 nm.** Absorption by the colored dissolved organic component (C) was measured directly by placing a 0.2  $\mu\text{m}$  filter cartridge on the intake port of one of the ac9s. This measurement was subtracted from the total absorption (Fig. 2C) measured with a second ac9, resulting in particulate absorption, which was deconvolved into phytoplankton (A) and colored particulate material (B) components using the model of Roesler et al. (1989). Where  $a_{\text{CDOM}}$  is not shown for these noon time casts the nearest cast value was used in the model.

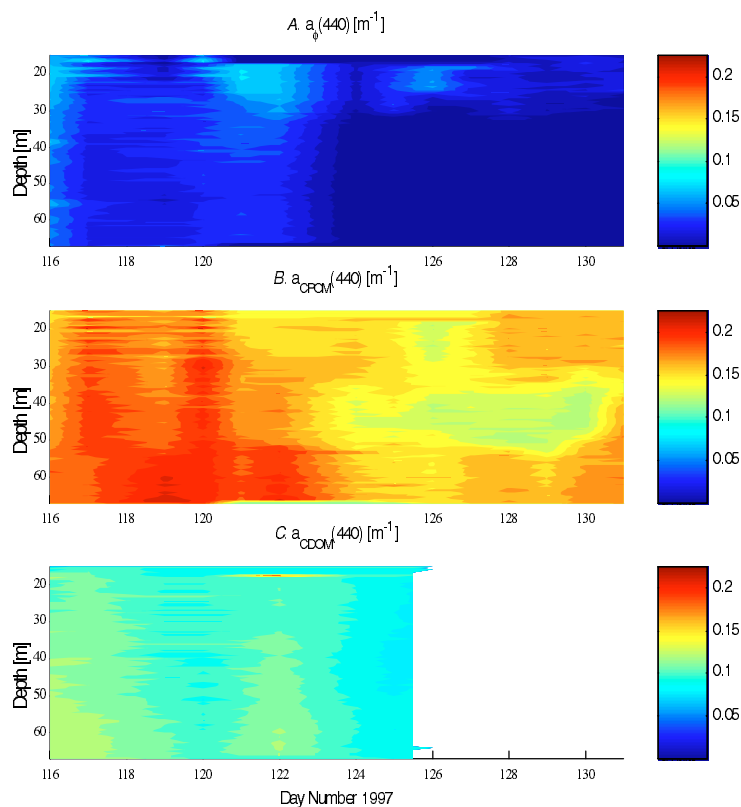


**Figure 4. Hydrographic conditions during the second CMO cruise in April 1997.** A. Temperature, B. Salinity, C.  $\sigma_T$ . Data shown is from daily noon time casts. The data have not been detided nor has there been corrections for the internal waves which were observed during this period.





**Figure 5.** *Inherent optical properties measured during the second CMO cruise in April 1997. A. Attenuation, B. scattering, and C. absorption at 440 nm were measured in situ with an ac9. The scale for the absorption is different from the attenuation and scattering to highlight features.*



**Figure 6.** *Absorption properties of the phytoplankton (A), colored particulate material (B), and colored dissolved organic material (C) during the second cruise. Components separated as discussed in Figure 3.*